

# Biodiesel from Algae oil

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## Algaculture – At a glance

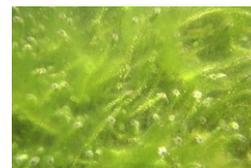
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### What are Algae?

**Algae range from small, single-celled organisms to multi-cellular organisms, some with fairly complex and differentiated form.** Algae are usually found in damp places or bodies of water and thus are common in terrestrial as well as aquatic environments.

**Like plants, algae require primarily three components to grow: sunlight, carbon-dioxide and water. Photosynthesis is an important bio-chemical process in which plants, algae, and some bacteria convert the energy of sunlight to chemical energy.**

**The existing large-scale natural sources of algae are: bogs, marshes and swamps - salt marshes and salt lakes.** Micro-algae contain lipids and fatty acids as membrane components, storage products, metabolites and sources of energy. Algae contain anything between 2% and 40% of lipids/oils by weight.



More information on different algae varieties, harvesting techniques and cultivation can be found here: [http://en.phyco.org/wiki/Main\\_Page](http://en.phyco.org/wiki/Main_Page)

### How to harvest Algae?

**The photo-bioreactor is the main equipment used to harvest algae.** Photo-bioreactors can be set up to be continually harvested (like the majority of the larger cultivation systems), or by harvesting a batch at a time (like *polyethylene bag cultivation*). A batch photo-bioreactor is set up with nutrients and algal seed, and allowed to grow until the batch is harvested. A continuous photo-bioreactor is harvested, either continually, as daily, or more frequently.

More detailed information on cultivation and harvesting can be found here: [http://www.castoroil.in/reference/plant\\_oils/uses/fuel/sources/algae/biodiesel\\_algae.html](http://www.castoroil.in/reference/plant_oils/uses/fuel/sources/algae/biodiesel_algae.html)

### Challenges in Algaculture

According to an article published in May 2007 by the *Nature* magazine <sup>[19]</sup>, Algae can also be picky:

- too much direct sunlight can kill them,
- temperature must be held steady,
- overcrowding will inhibit their growth,
- the “waste” oxygen they produce must be continually removed from the water,
- open algal ponds are subject to evaporation and rainfall, which cause salinity and pH imbalances, and
- local species of algae often overgrow the desired strain.

## About Biodiesel from Algae oil

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### Less dependence on fossil fuels, but...

*“The use of vegetable oil as fuel might seem of no importance in our times. However, such products can gain importance in the course of time and reach an equal status compared with today's petroleum and these coal-tar products”,* said Dr. Rudolf Diesel in 1912.

*“What happens now if people are all geared up for biofuels, but the market's not there?”* asks Doug Henston, (CEO of Solix Biofuels) in 2007. <sup>[19]</sup>

## Algaculture for Biodiesel production

**Algal-oil processes into biodiesel as easily as oil derived from land-based crops.** The difficulties in efficient biodiesel production from algae lie not in the extraction of the oil, but in finding an algal strain with a high lipid content and fast growth rate that isn't too difficult to harvest, and a cost-effective cultivation system (i.e. type of photo-bioreactor) that is best suited to that strain.

**Micro-algae have much faster growth-rates than terrestrial crops.** The per unit area yield of oil from algae is estimated to be from between 5,000 to 20,000 gallons (18,927 to 75,708 litres) per acre, per year; this is 7 to 31 times greater than the next best crop, palm oil (635 gallons or 2,404 litres).



**The production of algae to harvest oil for biodiesel has not yet been undertaken on a commercial scale, but feasibility studies have been conducted to arrive at the above yield estimate.** In addition to its projected high yield, algaculture — unlike crop-based biofuels — does not entail a decrease in food production, since it requires neither farmland nor fresh water. Many companies are pursuing the development of algae bioreactors for various purposes — including biodiesel production and CO<sub>2</sub> capturing.<sup>[15]</sup>

More information regarding this topic and related news and developments can be found here: <http://www.oilgae.com>

## Advantages of Biodiesel from Algae oil

Producing biodiesel from algae has been touted as the most efficient way to make biodiesel fuel. The main advantages of deriving biodiesel from algae oil include:

- rapid growth rates,
- a high per-acre yield (7 to 31 times greater than the next best crop — palm oil),
- certain species of algae can be harvested daily,<sup>[17][18]</sup>
- algae biofuel contains no sulphur,
- algae biofuel is non-toxic,
- algae biofuel is highly bio-degradable, and
- algae consume carbon dioxide as they grow, so they could be used to capture CO<sub>2</sub> from power stations and other industrial plant that would otherwise go into the atmosphere.

## Research and development efforts

**Currently most research into efficient algal oil production is being done in the private sector,** but if predictions from small scale production experiments bear out then using algae to produce biodiesel may be the only viable method by which to produce enough automotive fuel to replace current world gasoline usage, according to U.S. Department of Energy.<sup>[4]</sup>

**In the short term, a handful of early-stage companies working on algae want to produce Algae oils for biodiesel production,** replacing a significant proportion of the diesel fuel that currently serves about one-third of transport needs in the United States.

**Research into algae for the mass-production of oil is mainly focused on micro-algae. The preference towards micro-algae is due largely to its less complex structure, fast growth rate, and high oil content.** Some species of algae are ideally suited to biodiesel production due to their high oil content — sometimes topping out near 50%. **Some commercial interests into large scale algal-cultivation systems are looking to tie in to existing infrastructures, such as coal-fired power plants or sewage treatment facilities.** This approach not only provides the raw materials for the system, such as CO<sub>2</sub> and nutrients; but it changes those wastes into resources.



A feasibility study using marine micro-algae in a photo-bioreactor is being done by *The International Research Consortium on Continental Margins* at the International University Bremen.<sup>[5]</sup>

## Patents in the Algae oil sector

There are a number of patents of photo-bioreactor and algae pond layouts as well as optimization processes, but the procedure of production biodiesel from Algae oil is fairly simply. We can predict that more photo-bioreactor, pond layouts as well as new processes of production will emerge as more R&D is being conducted.

At present most companies in the sector are early stage start-ups and involved in R&D rather than commercialisation. To date, none has launched full commercialisation/industrialization of biodiesel from Algae oil on a large scale.

Patents could prove to be play important factor in the future, especially when companies start raising money from venture capital (VC) firms which tend look at intellectual property as well as technological know-how and expertise.

## Main obstacles to realization

Besides the challenges in Algaculture, there are some other obstacles to the realization of Algae oil projects:

- **Financing.** Although specialized VC firms in this sector are rare, there have been some interesting developments recently – notably with the involvement of big players like *Khosla Ventures* among others.
- **Technology.** Most companies only conduct R&D and are only nearing commercialisation in years to come.
- **Competition.** There are many small start-up companies in the sector. We can assume that some bigger companies will emerge out of the group of early-stage businesses – potentially making market-entry more difficult.
- **Intellectual property.** As of now patents do not really play a role yet. But in the foreseeable future, especially when the technology becomes mature and the companies are nearing commercialisation, patents could play an important role in this sector.

## Scepticism vs. Optimism

### No operating large-scale projects yet

Several companies have issued press releases about technologies using closed photo-bioreactors to produce bio-fuels from algae, claiming “enormous” amounts of biomass that can be turned into liquid fuels at low cost. Sadly, after decades of development, none of those projects have worked on a large scale or over a long time period.<sup>[2]</sup>

From 1978 to 1996, the U.S. National Renewable Energy Laboratory (NREL) experimented with using algae as a biodiesel source in the “Aquatic Species Program”.<sup>[13]</sup> Today most R&D efforts are being done in the private sector, with some promising concepts on the market but none fully commercialized.

### Recent VC investments in Algal companies

But then again, “[...] a *handful of pioneers are trying to bring algae-based biofuels back from a near-death experience*”, reports Amanda Leigh Haag in her article “*Algae bloom again*” published in *Nature* magazine in May 2007.<sup>[19]</sup> Here are some examples of recent VC investments in algal companies:

- As a matter of fact, Green Fuel Technologies so far has raised \$20 million from venture capital firms that finance early-stage companies and so-called ‘disruptive’ technologies.
- LiveFuels has raised \$10 million in 2007 and would like to raise another \$35 million to set it on its way to its target of making biocrude — the precursor of biodiesel — from algae for \$1 per gallon by 2010.

- Another algal company, Solazyme raised some \$8 million, plus \$2 million in debt in December 2005.

See also: *Investment firms interested in Algal companies.*

## Innovative concepts

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### Combined geothermal use and biodiesel production

An innovative concept comes from Infinifuel Biodiesel LLC. The company is the first to build a geothermal powered and heated biodiesel plant in November 2006 and hence is combining the best of both worlds – geothermal energy and renewable biodiesel production from algae oil. Their aim is stated clearly – “to be the leader in biofuel production, using Nevada’s renewable geothermal resources to heat and power the plants”.



Furthermore, Infinifuel Biodiesel LLC aims to be a “zero waste” company and declares publicly: “We are looking for beneficial uses for everything we produce, from glycerine to algae biomass. We have partnered with some diverse industries, which can use our by-products in an environmentally sensitive and responsible way.”

### Biodiesel from sewage ponds

On May 11<sup>th</sup>, 2006 the Aquaflow Bionomic Corporation in Marlborough, New Zealand announced that it had produced its first sample of biodiesel fuel made from algae found in sewage ponds. Unlike previous attempts, the algae were naturally grown in pond discharge from the Marlborough District Council’s sewage treatment works. <sup>[11]</sup>

A recent paper from Michael Briggs, at the UNH Biodiesel Group, offers estimates for the realistic replacement of all vehicular fuel with biodiesel by utilizing algae that have a natural oil content greater than 50%, which Briggs suggests can be grown on algae ponds at wastewater treatment plants. <sup>[12]</sup> These oil-rich algae can then be extracted from the system and processed into biodiesel, with the dried remainder further reprocessed to create ethanol.



## Algal companies specialized in Biodiesel production

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The following is a list of companies developing processes for the production of biodiesel from algae oil.

- **Enhanced Biofuels & Technologies ([www.ebtplc.com](http://www.ebtplc.com))** develops of multiple vegetable oil Biofuel technologies. The EBT algae process combines a bioreactor with an open pond, both using waste CO<sub>2</sub> from coal-fired power plant flue gases as a fertilizer for the algae. The biodiesel and ethanol produced can be sold, or used as an alternative fuel. Emissions are reduced up to 82%. EBT’s headquarters are in London, UK and the company has a biofuel R&D centre in India.
- **GreenFuel Technologies ([www.greenfuelonline.com](http://www.greenfuelonline.com))** - *Emissions-to-Biofuels*<sup>™</sup> process harnesses photosynthesis to grow algae, capture CO<sub>2</sub> and produce high-energy biomass. Retrofitting fossil-fired power plants and other anthropogenic sources of carbon dioxide, the algae can be economically converted to solid fuel, methane, or liquid transportation fuels such as biodiesel and ethanol.

In December 2005 GreenFuel Technologies secured \$11 million in the 2<sup>nd</sup> round of financing from *Draper Fisher Jurvetson* and *Access Private Equity LLC*. In April 2006 the company raised a further \$7 million from *Polaris Venture Partners*.

- **GreenShift** ([www.greenshift.com/news.php?id=97](http://www.greenshift.com/news.php?id=97)) has a license agreement with Ohio University for its patented bioreactor process based on a newly discovered iron-loving cyanobacterium (blue-green algae), through their subsidiary Veridium ([www.veridium.com](http://www.veridium.com)), for the purpose of air pollution control of exhaust gas streams from electrical utility fossil-fuelled power generation facilities. Once the algae grow to maturity, they fall to the bottom of the bioreactor and are harvested for fuel or fertilizer.

GreenShift's shares are traded on the OTC-BB in New York. The company owns majority stakes in the following subsidiary companies – *GS CleanTech Corporation, GS AgriFuels Corporation, GS EnviroServices, GS Carbon Corporation* and *GS Energy Corporation*.

- **Solazyme** ([www.solazyme.com](http://www.solazyme.com)) is devoted to harnessing the energy-harvesting machinery of various species of algae to produce valuable products. The company utilizes proprietary genetic engineering methods to develop and optimize commercially relevant biochemical pathways for production of hydrocarbons (for energy and specialty chemicals) & bioactive compounds.

In December 2005 Solazyme announced it had raised \$8 million, plus \$2 million of debt. *The Roda Group* led the financing, with participation from *Harris & Harris Group* and other undisclosed investors.<sup>[20]</sup>

- **LiveFuels** ([www.livefuels.com](http://www.livefuels.com)) - A national alliance of labs and scientists dedicated to transforming algae into biocrude by the year 2010. Working on breeding various strains of algae, driving down the costs of harvesting algae and extracting fats and oils from the algae.

In May 2007 LiveFuels announced a first round of \$10 million, led by David Gelbaum of the *Quercus Trust* – a major donor to conservation advocacy and environmental organizations.

- **Valcent Products** ([www.valcent.net/news\\_detail.sstg?id=36](http://www.valcent.net/news_detail.sstg?id=36)) has developed a high density vertical bio-reactor for the mass production of oil bearing algae while removing large quantities of CO<sub>2</sub> from the atmosphere. This new bio-reactor is tailored to grow a species of algae that yields a large volume of high grade vegetable oil, which is very suitable for blending with diesel to create a bio-diesel fuel.
- **Aquaflow Bionomics Corporation** ([aquaflowgroupcom.axiion.com](http://aquaflowgroupcom.axiion.com)), New Zealand-based, has set itself the objective to be the first company in the world to economically produce biofuel from wild algae harvested from open-air environments and to market it.
- **Infinifuel Biodiesel** ([www.infinifuel.com](http://www.infinifuel.com)) - Wabuska Nevada is home to a unique biodiesel project under development and is being touted as the world's first geothermal-powered and heated biodiesel plant. The existing geothermal power plant features two production wells and seven power production units creating more than 5 MW of electricity, according to Infinifuel. The power plant will provide 2 MW of electricity and 104°C (220°F) steam to the biodiesel facility, which is nearing completion. The company has over 300 acres to grow oil-seed and develop algae ponds on site.
- **Solix Biofuels** ([www.solixbiofuels.com](http://www.solixbiofuels.com)) is a developer of massively scalable photo-bioreactors for the production of biodiesel and other valuable bio-commodities from algae oil. Solix' closed photo-bioreactors allow fossil-fuel power plant exhaust to be captured through the growing system. The algae growth rates increase in the presence of the carbon dioxide that would otherwise be emitted into the atmosphere.

Solix Biofuels has solid backing from a local private investor, and says it plans to develop its technology as far as it can on its own before seeking venture capital. Solix believes it can build a system that's competitive on a small commercial scale with between \$5 million and \$15 million, and says it has sufficient backing to do this.

- **Algoil** ([www.algoil.com](http://www.algoil.com)) is a pioneer project focusing on the production of biodiesel/biomass from micro-algae. The target is to use the rest of the extracted biomass to make food, biofuel, hydrogen, paper, or simply burning it like charcoal.
- **PetroAlgae** ([www.petroalgae.com](http://www.petroalgae.com)) is commercializing environmentally-friendly algae developed by a research team at Arizona State University that generates over two hundred times more oil per acre than crops like soybeans. Using a cost-effective, modular cultivation process that can be massively scaled, PetroAlgae will produce renewable feedstock oils for use in applications such as transportation fuels, heating oil, and plastics.

PetroAlgae is a 95%-owned subsidiary of XL TechGroup, a conglomerate diversified in biotechnologies, life sciences and environmental technologies. <sup>[17]</sup> XL TechGroup is listed since October 2006 on London's AIM market and secured a new mezzanine borrowing facility of \$20 million in January 2007.

- **Aurora BioFuels** ([www.aurorabiofuels.com](http://www.aurorabiofuels.com)) is a California-based renewable energy company exploring new sources of feedstock for the production of biofuels. In particular, Aurora focuses on utilizing microalgae to generate bio-oil, which can be converted into biodiesel.

## Investment firms interested in Algal companies

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### Venture capital firms

- United States, Access Private Equity
- United States, Draper Fisher Jurvetson (DFJ)
- United States, Harris & Harris Group
- United States, Khosla Ventures
- United States, Noventi (formerly Cypress Ventures)
- United States, Polaris Venture Partners
- United States, The Roda Group

### Corporate investors

- Australia, XL TechGroup

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